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ORIGINAL ARTICLE

NUMERICAL INVESTIGATION OF EFFECT OF NANOPARTICLES DIAMETER ON FLOW AND HEAT TRANSFER IN LID-DRIVEN CAVITY WITH AN INSIDE HOT OBSTACLE FILLED WITH NANO-FLUID

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ABSTRACT: The present paper focuses on problem of mixed convection fluid flow and heat transfer of Al_2O_3-water nanofluid with temperature and nanoparticles concentration dependent thermal conductivity and effective viscosity inside Lid-driven cavity having a hot rectangular obstacle. The governing equations are discretized using the finite volume method while the SIMPLER algorithm is employed to couple velocity and pressure fields. The obtained results showed that the average Nusselt number for all range of solid volume fraction decreases with increase in the diameter of nanoparticles.

KEYWORDS: Nanofluid, Variable properties, Solid volume fraction, Heat transfer, Diameter of nanoparticles

INTRODUCTION

Nanofluids are created by suspending nanometer-sized particles (less than 100 nm) in a pure fluid such as water, ethylene glycol or propylene glycol. The first to coin the "nanofluids" for these fluids with superior thermal properties was Choi, 1995. Several investigates on mixed convection in single or double lid-driven enclosure flow and heat transfer including different cavity geometries and configurations, different base fluids and boundary condition have been reported. Particularly in recent years some interesting researches have been done such as Talebi *et al.*, (2010); Rabbani bidgoli *et al.*, (2012); Saedodin and Hemmat esfe (2012) and Hemmat esfe *et al.*, (2012). Another work that was done by Nikfar and Mahmoodi (2012) also approved the above statement. They studied about natural convection in a square cavity filled with Al_2O_3–water nanofluid. The horizontal walls of the cavity were insulated while left and right wavy side walls of cavity were maintained at high and low constant temperatures. They demonstrated that increase in the volume fraction of the nanoparticles, the average Nusselt number of the hot wall also increases. Motivated by the investigations mentioned above, the purpose of the present work is to consider mixed convection flows of Al_2O_3–water nanofluid in a square cavity with an inside heated obstacle and a moving upper lid that moves uniformly in the horizontal plane. Also the effects of the Richardson number, diameter and solid volume fraction of the Al_2O_3 nanoparticles on the flow and thermal fields and heat transfer inside the cavity are studied.

PHYSICAL MODELING AND GOVERNING EQUATION

Figure 1 displays a two-dimensional Lid-driven square cavity with an inside heated obstacle. The height and the width of the square cavity are denoted L. The cavity is filled with a suspension of Al_2O_3 nanoparticles in water. Bottom and vertical walls are insulated whereas the top moving wall is kept at low temperature T_c. In order to induce the buoyancy effect, an obstacle with a relatively higher temperature, T_h, is located on the bottom wall of the cavity.

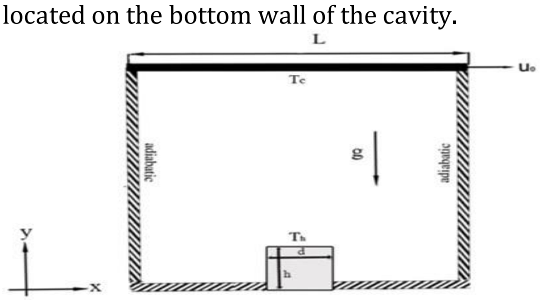

Figure 1: Schematic view of square cavity considered in this study

The nanofluid in the enclosure is Newtonian, incompressible and laminar. In addition, it is assumed that both the fluid phase and nanoparticles are in the thermal equilibrium state and they flow with the same velocity. The thermophysical properties of nanoparticles and the water as the base fluid at T = 25°C are presented in Table1.

Table 1: Thermophysical properties of water and nanoparticles at T =25°C

Physical properties	Fluid phase (Water)	Solid (Al_2O_3)
Cp(J/kg k)	4179	765
ρ (kg/m3)	997.1	3970
K (W m-1 K-1)	0.6	25
$\beta\times10^{-5}$ (1/K)	21.	0.85
$\mu\times10^{-4}$(Kg/ms)	8.9	……..

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The thermal conductivity and the viscosity of the nanofluid are taken into consideration as variable properties; both of them change with volume fraction and temperature of nanoparticles. Under the above assumptions, the system of governing equations is:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial x}+\upsilon_{nf}\nabla^2 u, \quad (2)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial y}+\upsilon_{nf}\nabla^2 v+\frac{(\rho\beta)_{nf}}{\rho_{nf}}g\Delta T, \quad (3)$$

And

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\nabla^2 T. \quad (4)$$

The dimensionless parameters may be presented as

$$X=\frac{x}{L},\ Y=\frac{y}{L},\ V=\frac{v}{u_0},\ U=\frac{u}{u_0} \quad (5)$$

$$\Delta T=T_h-T_c,\ \theta=\frac{T-T_c}{\Delta T},\ P=\frac{p}{\rho_{nf}u_0^2}.$$

Hence,

$$\mathrm{Re}=\frac{\rho_f u_0 L}{\mu_f},\ Ri=\frac{Ra}{\mathrm{Pr}.\mathrm{Re}^2},\ Ra=\frac{g\beta_f\Delta T L^3}{\upsilon_f\alpha_f},\ \mathrm{Pr}=\frac{\upsilon_f}{\alpha_f}. \quad (6)$$

The dimensionless form of the above governing equations (1) to (4) become **(7)**

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{\upsilon_{nf}}{\upsilon_f}\frac{1}{\mathrm{Re}}.\nabla^2 U \quad (8)$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{\upsilon_{nf}}{\upsilon_f}\frac{1}{\mathrm{Re}}.\nabla^2 V+\frac{Ri}{\mathrm{Pr}}.\frac{\beta_{nf}}{\beta_f}\Delta\theta \quad (9)$$

And **(10)**

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{\alpha_{nf}}{\alpha_f}\nabla^2\theta$$

2.1. Thermal Diffusivity and Effective Density

Thermal diffusivity and effective density of the nanofluid are

$$\alpha_{nf}=\frac{k_{nf}}{(\rho c_p)_{nf}} \quad (11)$$

$$\rho_{nf}=\varphi\rho_s+(1-\varphi)\rho_f \quad (12)$$

2.2. Heat Capacity and Thermal Expansion Coefficient

Heat capacity and thermal expansion coefficient of the nanofluid are therefore

$$(\rho c_p)_{nf} = \varphi(\rho c_p)_s + (1-\varphi)(\rho c_p)_f \quad \textbf{(13)}$$

$$(\rho\beta)_{nf} = \varphi(\rho\beta)_s + (1-\varphi)(\rho\beta)_f \quad \textbf{(14)}$$

2.3. Viscosity

The effective viscosity of nanofluid was calculated by

$$\mu_{eff} = \mu_f (1+2.5\varphi)\left[1+\eta\left(\frac{d_p}{L}\right)^{-2\varepsilon}\varphi^{2/3}(\varepsilon+1)\right] \quad \textbf{(15)}$$

This well-validated model is presented by Jang *et al.*, (2007) for a fluid containing a dilute suspension of small rigid spherical particles and it accounts for the slip mechanism in nanofluids. The empirical constant ε and η are _0.25 and 280 for Al_2O_3, respectively. It is worth mentioning that the viscosity of the base fluid (water) is considered to vary with temperature and the flowing equation is used to evaluate the viscosity of water,

$$\mu_{H_2O} = (1.2723\times T_{rc}{}^{5} - 8.736\times T_{rc}{}^{4} + 33.708\times T_{rc}{}^{3} - 246.6\times T_{rc}{}^{2} + 518.78\times T_{rc} + 1153.9)\times 10^{6} \quad \textbf{(16)}$$

Where, $Trc = Log(T-273)$.

2.4. Dimensionless Stagnant Thermal Conductivity

The effective thermal conductivity of the nanoparticles in the liquid as stationary is calculated by the Hamilton and crosser (H-C model, 1962), which is:

$$\frac{k_{stationary}}{k_f} = \frac{k_s + 2k_f - 2\varphi(k_f - k_s)}{k_s + 2k_f + \varphi(k_f - k_s)} \quad \textbf{(17)}$$

2.5. Total Dimensionless Thermal Conductivity of Nanofluids

$$\frac{k_{nf}}{k_f} = \frac{k_{stationary}}{k_f} + \frac{k_c}{k_f} = \frac{k_s + 2k_f - 2\varphi(k_f - k_s)}{k_s + 2k_f + \varphi(k_f - k_s)} + c\,\frac{Nu_p d_f\,(2-D_f)D_f}{\Pr(1-D_f)^2}\,\frac{\left[\left(\frac{d_{max}}{d_{min}}\right)^{1-Df} - 1\right]^2}{\left(\frac{d\,max}{d\,min}\right)^{2-Df} - 1}\,\frac{1}{d_p} \quad \textbf{(18)}$$

This model was proposed by Xu *et al.*, (2006) and it has been chosen in this study to describe the thermal conductivity of nanofluids. c is an empirical constant(e.g. c = 85 for the deionized water and c = 280 for ethylene glycol) but independent of the type of nanoparticles. Nu_p is the Nusselt number for liquid flowing around a spherical particle and equal to two for a single particle in this work. The fluid molecular diameter df =4.5*10^{-10}(m) for water in present study. The fractal dimension D_f is determined by:

$$D_f = 2 - \frac{\ln\varphi}{\ln\left(\frac{d_{p,min}}{d_{p,max}}\right)}$$

Where, $d_{p,max}$ and $d_{p,min}$ are the maximum and minimum diameters of nanoparticles, re spectively. Ratio of minimum to maximum nanoparticles $d_{p,min}/d_{p,max}$ is R.

$$d_{p,max} = d_p.\frac{D_f - 1}{D_f}\left(\frac{d_{p,min}}{d_{p,max}}\right)^{-1}$$

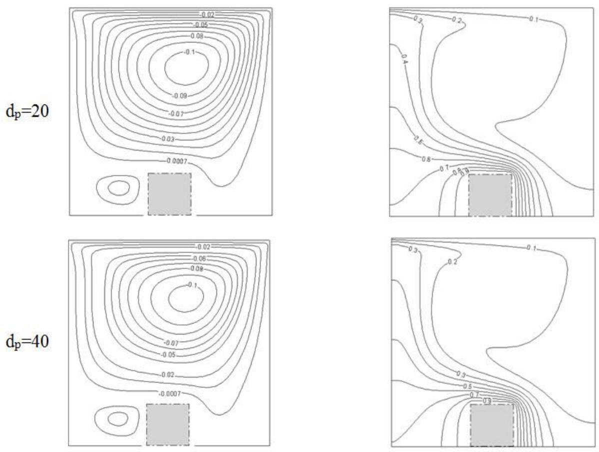
$$d_{p,min} = d_p.\frac{D_f - 1}{D_f}$$

NUMERICAL METHOD

Governing equations for continuity, momentum and energy equations associated with the boundary conditions in this investigation were calculated numerically based on the finite volume method and associated staggered grid system, using FORTRAN computer code. The SIMPLE algorithm is used to solve the coupled system of governing equations. The convection terms is approximated by a hybrid-scheme which is conducive to a stable solution. In addition, a second-order central differencing scheme is utilized for the diffusion terms. The algebraic system resulting from numerical discretization was calculated utilizing TDMA applied in a line going through all volumes in the computational domain.

RESULTS AND DISCUSSION

Thermal behavior and flow characteristics in square cavity filled with nanofluid which has a movement upper lid with a square hot obstacle has been investigated via a numerical simulation based on finite volume method. The influence of parameters such as nanofluid solid volume fraction, nanoparticles diameter and Richardson number has been investigated on streamlines and isotherm lines separately. The cavity movement upper lid was preserved in high temperature while other walls have been assumed to be adiabatic. The reaction of buoyancy resulting from temperature difference is caused by obstacle and hot wall and shear force, resulting from upper lid movement caused in flow creation and heat transfer in the cavity. Figure 2 displays streamlines and isotherms changes on the basis of change in nanoparticles diameter dispersed in water at h=0.2 L, $\varphi = 0.05$, Ri=1 and w=0.2 L. In this parametric interval, streamlines show formation of a clockwise central primary cell above the obstacle which occupies a vast area of the cavity. Also a small vertex was formed in the space between obstacle and left adiabatic wall. Isotherm lines are also intensified in areas around isotherm walls while the distribution of these lines is very low in cavity central areas.



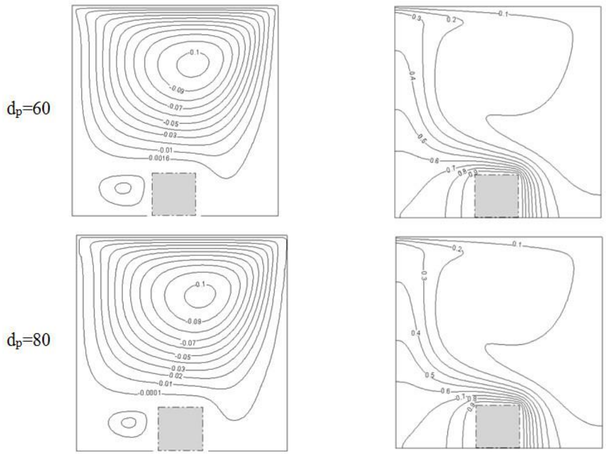


Figure 2: streamlines and isotherms in different diameter of nanoparticle in Ri=1, $\varphi = 0.05$, W=0.2L, T=320 and h=0.2L

With increasing nanoparticles diameter, no meaningful change happens in flow pattern in the cavity but the intensity of primary cell slightly deceases. Increase in nanoparticles diameter, too, causes decrease in the intensity of isotherm lines near the hot walls and this intensity decrease indicates decrease in temperature gradient. It is therefore expected that heat transfer slightly decreases in the cavity by increasing nanoparticles diameter.

CONCLUSION

In this paper, the effect of Al_2O_3/water nanofluid variable properties on mixed convection heat transfer and fluid flow in a two dimensional lid-driven square cavity with an inside hot obstacle on the bottom wall was studied numerically. The developed numerical code was validated by comparing the obtained results with those available in the literature. We get the following conclusions from the obtained results:

When the Richardson number and solid volume fraction is kept constant and the diameter is varying from 20 to 80 nm, it is evident that an increase in nanoparticle diameter doesn't significant change on the flow pattern and isotherm contours inside the cavity. The results have clearly indicated that the addition of Al_2O_3 nanoparticles has produced a remarkable enhancement on heat transfer with respect to that of the pure fluid.

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